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Identification of constitutive properties of composite materials under high strain rate loading using optical strain measurement techniques

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ABSTRACT

Optical techniques have been increasingly used in recent years for displacement and strain measurements in academic and industrial environments. These measurement methodologies evaluate deformation and strains by comparing the digital images of deformed and undeformed surfaces. Often a pattern, either regular or stochastic, depending on the technique used, is applied to the surface to allow the image comparison. Such optical techniques offer many advantages when used in challenging applications such as the characterisation of materials at high strain rates [1]. Traditionally, strain gauges can be used to obtain local strains with a well defined accuracy. However, at high strain rates, the response of the adhesive that bonds the sensor to the specimen may affect the measurements. Furthermore, with Polymer Matrix Composites (PMCs) localised heating may occur, which can have a deleterious effect on the measurement. Finally, a strain gauge will only provide information within the small area that it is bonded to, which may not be the location where the failure initiates. Optical techniques that are non-contact and full-field allow a high spatial resolution map of the strain over the whole surface of the specimen to be obtained without modifying the material behaviour with the measuring process. Moreover, the spatial and temporal resolution of full-field optical techniques depends on the hardware and not on the measuring methodology. Constant improvements in hardware, resulting from developments in Charge Coupled Devices (CCD) sensor technology and enhanced computing power has enabled parallel increases in the spatial and temporal resolution of such techniques to provide precise tools for high strain rate material characterisation.

To extend the application of PMCs to primary structures in an efficient manner, a robust methodology to evaluate their constitutive behaviour under high strain rate is required. The data could then be used to better inform material and component modelling [2]. In this paper, an experimental study of the high strain rate behaviour of both PMC and resin alone is described. The PMC test specimens are laminated from a unidirectional glass fibre reinforced epoxy prepreg. The effect of the resin on the material response is determined by using specimens made only from the epoxy matrix used in the prepreg.

The high strain rate loading is applied using an Instron VHS High Strain Rate servo-hydraulic tensile test machine operated with a cross-head speed ranging from 1 to 5

m/s. The strain rates that can be achieved with the VHS machine are low in comparison to those achieved with the Hopkinson bar, which is traditionally used in high strain rate behaviour studies. The VHS machine provides better optical access and opportunities for illumination of the specimen necessary to the application of the optical techniques [3]. In this study two optical techniques are used: Digital Image Correlation (DIC) and the Grid method (GM). The images of the specimen are acquired with two different cameras, a Photron SA-3 and a MotionPro X3. For comparison purposes strain measurements are also recorded using strain gauges. DIC allows the deformation field to be extracted from the images by comparing the pixel intensity array subset of two images; this requires a random speckle pattern over the specimen's surface [4]. GM evaluates the strain by analysing the phase of the light reflected by a regular grid applied on the specimen surface [5].

In the paper, the obtained strain data are used to evaluate the Young's modulus and the Poisson's ratio of the PMC and the epoxy resin. The Virtual Fields Method (VFM) [6], a technique aimed at processing full-field strain data using the principle of virtual work to solve the inverse problem directly, is used to evaluate the same material properties. A comparison between the various sets of results is presented. The critical issues arising from conducting high strain rates tests in conjunction with optical strain measurements techniques are identified.

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